

Towards cheaper control centers

31807

p. 8

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ABSTRACT : Today, any approach to the design of new space systems must take into consideration an important constraint, namely costs. This approach is our guideline for new missions and also applies to the ground segment, and particularly to the control centre. CNES has carried out a study on a recent control centre for application satellites in order to take advantage of the experience gained. This analysis, the purpose of which is to determine, *a posteriori*, the costs of architecture needs and choices, takes hardware and software costs into account and makes a number of recommendations.

PREAMBLE

The Télécom2 satellite control computer system (SICS : *Système Informatique de Contrôle des Satellites*) is the continuation of the SICS-P (provisional system), which was used for the positioning and station keeping of the Télécom2A and Télécom2B satellites until the switchover from SICS-P to SICS (October 20, 93). Since this date, the SICS has been controlling 2 station keeping satellites.

This system was developed by the Information Processing sub-directorate of CNES, the prime contractors being the Matra Marconi Space France industrial group and Syseca.

1 - THE TELECOM2 SYSTEM

Designed as the continuation of the Télécom1 programme, the Télécom2 programme consists, in operational mode, of 3 satellites placed in geostationary orbits at -8°, -5° and 3° EAST. Two are in operation and 1 is on standby. Each satellite is made up of a stabilized 3-axis platform of EUROSTAR type, with 3 payloads and associated antennae for the following 3 missions:

- 12/14 GHz for new communication services in metropolitan France,
- 7/8 GHz for links specific to the Ministry of Defence,
- 4/6 GHz for classical links with the Overseas Territories,

2 - GROUND SEGMENT FOR TELECOM2 POSITIONING AND STATION KEEPING

The ground segment for Télécom2 positioning and station keeping comprises specific facilities and is also supported by CNES multimission facilities used for emergency purposes and in the launch and early orbit phase.

These specific facilities are :

- 2 Specialized Control Centres (SCC) with identical functions and capable of providing TTC control of 3 satellites 24 hours a day. Two satellites may be kept in a geostationary orbit while the third one is being positioned. The SCC have facilities for telemonitoring and remote activation of the station keeping control centres, in particular in order to initiate tracking measurements,
- 4 Network Control Centres for the 3 payloads. Each of these centres receives from the operational SCC, the telemetry data required to monitor the payloads,
- 4 4/6 GHz stations dedicated to TTL control of the 3 satellites,
- 3 7/8 GHz stations for traffic control, capable of providing TTL support simultaneously to 2 satellites,
- 3 4/6 GHz stations, Overseas (Réunion, Guiana), operating as "repeaters" to perform tracking measurements by turn-around with the previous 4 stations. The SCC provides simplified telemonitoring of these stations,
- 1 X25 network for specific Télécom2 data transmission (Réseau de Transmission de Données-Télécom2), which links the SCC to the stations and the NCCs.

3 - ENTITIES OF THE TELECOM2 CONTROL CENTRE

To carry out its mission, the Specialized Control Centre consists of several entities:

- the Satellite Control Computer System (SICS), responsible for real time tracking, telemetry and command functions and for their distribution to other entities, as well as for deferred batch processing functions,
- the orbitography computer (SUN hardware), using tracking measurements preprocessed by the SICS for orbit determination, prediction and computation of operations,
- Complementary Computer Facilities (CCF), which are micro-computers (PC), responsible for real time and deferred data processing,
- the cyphering bay,
- the Expert System (SUN hardware), which performs deferred analysis of data from the SICS,
- the Connection Unit to the RTD, which is the network entry point,
- the dynamic simulator (Digital hardware), used for practising or exercise purposes,
- the GASCON system (Hewlett-Packard hardware), for the telemonitoring and remote activation of stations and for initiating tracking measurements and station reconfigurations,
- the Technical Memory Management System (TMMS - SUN hardware), which performs deferred formatting of data from the SICS.

4 - SICS

The SICS real time functions are as follows :

- . management of data received and to be transmitted to the 2 communication networks (dedicated and mulimissions networks),
- . permanent processing of 4 TM data flows for automatic or visual monitoring and for data exportation. The 4th TM flow comes either from the simulator or from a redundant station,
- . preparation and sending of necessary commands, whether or not cyphered, possibly for 4 entities,
- . preprocessing of tracking measurements used by the operator to assess results and decide upon action to be taken, and compression of these measurements

- . preprocessing of the station calibration measurements,
- . storage of data received and of part of the processed data, for later analysis,
- . real time and deferred distribution of information to the other user entities of the SCC and to the NCCs.

The SICS deferred functions are :

- . supply of data for orbitography and operation processing,
- . all telemetry data classifying (trend analysis and replay), necessary for the analysis of changes in the satellites and for investigations in case of anomaly.
- . selective or statistical analysis of events recorded in the various logbooks,
- . management of real time block diagrams used for telemetry viewing at the SCC and the NCCs,
- . management of the so-called operational data, i.e. telemetry, commands, monitoring files, telemetry pages, etc.,
- . data backup for later use.

All these functions are implemented with a level of performance matching mission requirements and with ergonomics adapted to non computer experts for operations related to the basic functions (real time and TM data classification).

4.1 - General architecture of the SICS

This architecture is made up of 4 main entities, 3 of which operate on Digital hardware interconnected via an Ethernet network :

- a DEC MIRA "FRONT-END" computer, mainly responsible for real time processing,
- a DEC MIRA "BACK-END/DATA SERVER" computer, in charge of deferred processing, data storage and archival, data exportation to local or remote subscribers, and importation of graphic pages (block diagrams) from internal graphic servers,
- five dual-screen operator workstations, responsible for viewing real time or deferred telemetry, preparing commands and managing dialogue with the operator as well as feeding the video distribution system for the command and dwell page,
- the Graphic Server entity (3 HP computers), in charge of creating and viewing the graphic block diagrams, converting block diagrams dedicated to the NCCs and generating video TM pages.

The FRONT-END processor is connected via the RTD to the TTC Télécom2 stations and, through synchronous serial links to the 2 GHz stations and the satellite simulator on the one hand, and to the command cyphering bay, on the other hand.

The MIRA computers consist of two redundant microvax processors and a line switch. Each processor has its own input/output lines and other I/O lines connected to the switch. Only the nominal processor is connected via the switch to the external I/O lines, whereas the redundant processor is separated from these lines. An automatic system is used for failure detection and switching external lines from the nominal processor to the redundant one.

The MIRA computer manages the automatic switching of external links and allows free selection of the role of the processors, which may be :

- hot redundancy: applications only using inputs/outputs through a specific line may be run in parallel on each processor,
- active/standby redundancy : applications using inputs/outputs through a switchable line are active on the nominal processor and on standby on the redundant processor. The switching system activates them when changing from the nominal processor to the redundant processor,
- dedicated processor : a processor runs applications, without redundancy with the other.

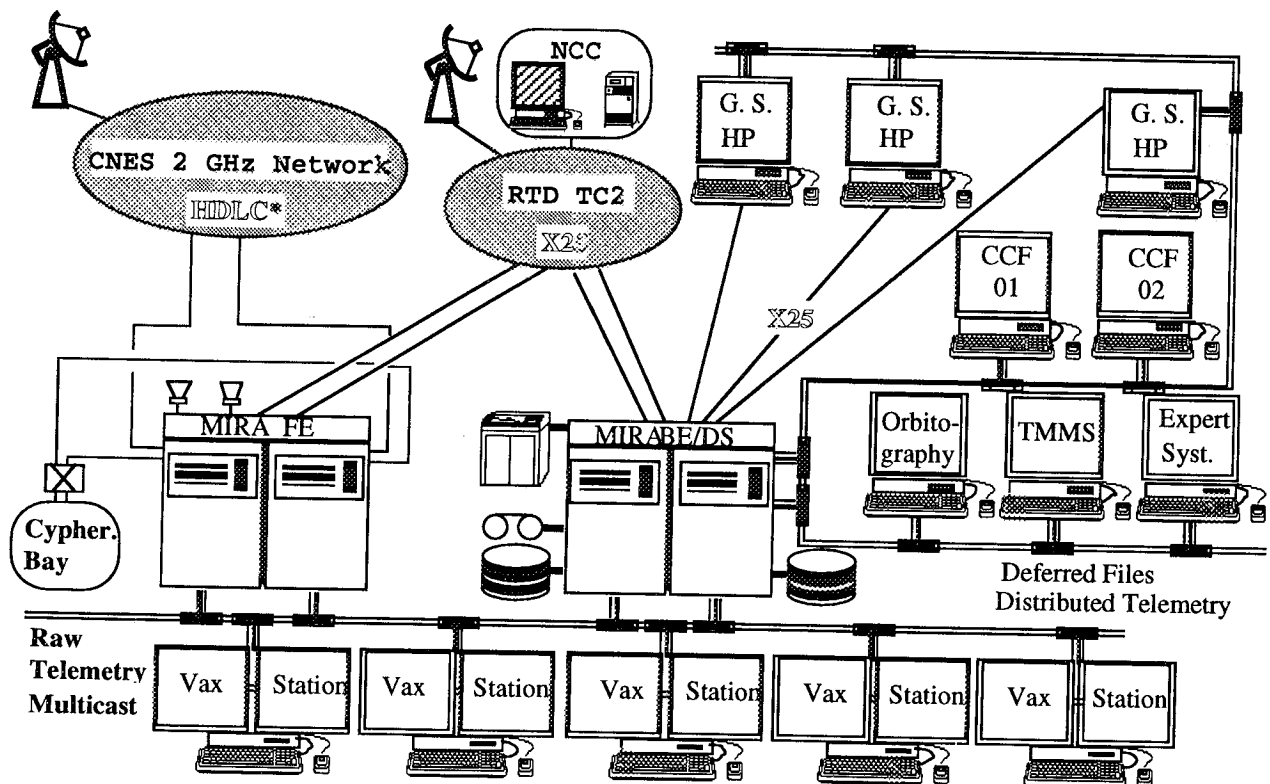


Fig. 1: Architecture of the SICS within the Télécom2 ground segment

4.2 - Functional description of the SICS

The system architecture has the main following features :

- reception and processing of raw telemetry lines by the MIRA front-end processor,
- multicast, on the local network, of raw telemetry data, derived parameters and control results by the MIRA front-end processor following processing,
- processing of data distributed by the MIRA back-end processor/data server and transmission to local and distant subscribers,
- processing of data distributed to the operator workstations for viewing purposes.

The nominal processor of the front-end computer receives telemetry data from the TTC stations and/or the dynamic simulator, processes this data in real time, line by line, every 1.2 seconds (line acquisition, parameter calibration and control), and multicasts the raw telemetry line, derived parameters and control results to the other elements ;
the nominal processor and the redundant processor of the back-end computer/data server simultaneously archive telemetry data received ;
the operator workstations process the TM blocks distributed to the network by the front-end computer to view telemetry and control alarms ;
the nominal processor of the back-end computer/data server processes TM blocks distributed to the network by the front-end computer for telemetry exportation to subscribers.

Telemetry replay is performed by reading the archived data on the back-end processor/data server and transmitting them to the front-end computer for processing;
the trend analysis is defined by the operator from his workstation. The nominal processor of the back-end computer/data server retrieves, processes and makes the archived data available for viewing purposes.

Tracking data are received by the front-end computer. They are compressed by the nominal processor of the back-end computer/data server.

Command transmission is performed by the front-end computer.

Synchronization is carried out by the nominal processor of the back-end computer/data server, which cyclically gets the universal time and transmits it to the other computers.

5 - COST ELEMENTS

5.1 - Hardware

An outstanding feature of the Télécom2 control centre and particularly of the SICS is the number of machines used. This may be explained by the following factors:

- the various origins of the different systems and sub-systems, resulting in the fact that each sub-system has its own dedicated machine without any attempt to optimize the use of such a machine (why should a machine not perform several deferred functions, and even real time functions?)
- availability constraints required by the satellite. For the SICS, the constraint imposed was a maximum unavailability of 5 minutes during the critical phases, concerning the telemetry and command functions. This made it necessary to double the number of microvax computers on each site. The availability factor must be globally taken into account and one must consider that an in-flight failure and a ground failure occurring simultaneously represent a double failure of the complete system or one must be aware of costs induced by the operation of the system.
- 24 hours a day operation, which results in constraints upon the workstations. The operators must have workstations which are both dedicated to a definite satellite and user friendly. This accounts for the number of workstations and the presence of double screens.

Costs induced by material maintenance are high (Fig 2) : using a several year old configuration is expensive and the costs increase with time. Its replacement by a more recent configuration or its upgrading using manufacturers' kits may be cost-effective. Such an operation is quickly depreciated if one consider cost saving at the maintenance level. Examples of this approach could be the conversion of SICS computers from micro VAX 3500 to micro VAX 4000/200 or the purchase of HP715 configurations instead HP835. These operations would be depreciated as of the third year of maintenance. Moreover, purchasing the operational configuration should be delayed as long as possible and, if possible, this configuration should not be supplied as of the development phase.

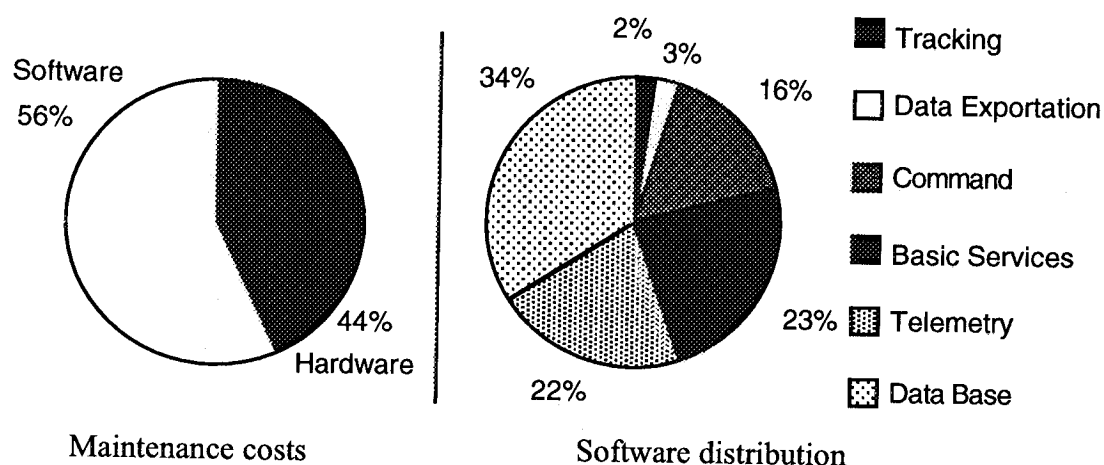


Fig 2: Maintenance cost estimate and size of application software per sub-system

5.2 - SOFTWARE

The SICS software performs many functions, offers great versatility of use and has been developed with high quality and documentation requirements. It thoroughly complies with its specifications and users are entirely perfectly satisfied.

However, one often forgets that any requirement, whether technical or quality related, has to be paid for and developments made on a fixed firm base do not show the price of each requirement. The industrialist must price a work, whereas neither the technical specifications nor the development rules are detailed in writing. Thus, he can only indicate a global amount. As an alternative, the development contracts could be divided into two parts: a specification phase resulting in proposals priced according to the requirements considered and with alternative proposals, then the fixed performance phase, which then could be implemented, knowing the costs and deadlines of each requirement. Precise knowledge of the costs is a factor which contributes to their reduction.

The process complexity was determined, considering the number of modules making up the processes, the size, complexity (cyclomatic number) and the number of calls for routines external to each module.

Efforts required to develop sub-systems (see project results in ref. [SICS 3]) are appropriate to their complexity and to the distribution non conformance reports. There is indeed a direct relationship between complexity and costs.

Among the technical facts which may be brought out because of their complexity, let us mention:

- the existence of local data bases on each workstation, which required the development of updating, storage and distribution procedures as well as monitoring their impact on the Ethernet network, in all, near 400 modules with more than 800 calls for other routines,
- it was not easy to develop the capacity to automatically issue commands for a telemetered event, as each operator workstation may issue commands (with exclusion mechanisms) to any satellite, and this function must be exclusive of the interactive command sessions. For information, just managing its inhibition needed 10 modules using 20 routines,
- management of the synchronous protocol specific to the CNES 2 GHz network and to the encoding rack required programming an input/output board, in all 32 modules using 72 routines,
- the Man Machine Interface requires many software programmes. It is present in all the functions and carries much weight in the production and presentation of information. If we consider only the processes entirely dedicated to this function, managing the MMI requires 111 modules using 225 routines, i.e. more than 3500 executable instructions.

Although it was necessary to develop delicate mechanisms for disk data recovery, the availability factor mainly relied on MIRA software for the switching of nominal computers to redundant computers and thus induced few developments.

Fig 2 shows the significant share of the basic services that manage external interfaces and coordinate the SICS operation. They are closely related to the hardware architecture. The volume of the telemetry sub-system is explained by the complexity of the deferred function part, processing of the satellite-ground interface and viewing (block diagrams, pages, etc.).

To reduce this complexity and therefore the related costs, the architectures must be simplified as follows :

- dedicate workstations, which corresponds to the operational reality and may simply be done by a "login" procedure,
- simplify the MMI, as there is no need to display all functions by means of windows and menus. It is not necessary to go backwards and risk operational errors, but prohibiting any keyboard entry and displaying all information in graphic form are expensive. Is an interface similar to that of office workstations really necessary for all functions ?
- avoid in-house protocols as far as possible, because they need to be programmed and maintained, whereas manufacturers tend to give them up,
- reduce customer-server links, as the SICS multicast feature is a very good concept and suppresses the transmitter-receiver link and should be extended to the distribution of raw and physical telemetry,
- think to satellite ground interface in terms of exploiting the data it carries,
- use CCSDS standards (software exists or will exist in a short period of time),
- any memory zone of the satellite and command stack especially has to be dumpable.

6 - CONCLUSION

The approach to space projects must be improved. To reduce ground costs, requirements must be adapted to needs. Margins must no longer be included in requests: if the constraint is "N", the supplier must be asked to provide "N" and not "N+X%", and, as each intermediary adds his own margin, constraints are reached, which are hard to fulfil and completely unjustified.

The complexity of satellite-ground interfaces must also be carefully assessed, CCSDS recommendations have to be taken into account,

Critical phases, with their need for availability and specific interfaces, must not affect the whole system life. Ideally, only the positioning should be critical and should be performed in a dedicated configuration.

Customizing the costs of each requirement is unquestionably a savings factor, whether this requirement is technical or methodological, and is achieved by custom designing the specification phase under a specific contract.

Multiplication of hardware configuration must be limited, whether by using common input-output services, sharing sub-system configurations or accepting the deterioration of some functions in case of failure, such as for example reconfiguring a deferred processing machine into a real time machine.

Fortunate as we are to have a product which offers many functions, we should take advantage of it by offering it, within a line of products, to other projects, which therefore will have a low cost basis (as development has already been done) for a precise assessment of the adaptations needed.

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